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Abstract

We have mapped the $C^{17}O/C^{18}O$ abundance ratio in three nearby molecular clouds (B335, L134 and p Oph), two of which are active star-forming regions. In p Oph, wc find evidence for abundance variations which we interpret as due to the underlying osygen isotopic abundance. Spatial variability, on solar mass scales may exceed that observed by factors of a few (1 to 5), due to line-of-sight averaging. We therefore suggest a spatial variability in the 170/180 oxygen abundance on solar mass scales, possibly resulting from local enrichment, Such a finding has important implications for our understanding of Galactic nuclear evolution. If such variations can find their way into forming stars, then we must view with suspicion conclusions based on differences between solar abundances (taken as typical of 5 Gyr ago) and those in the present-day interstellar medium. Such differences, in $^{17}O/^{18}O$, $^{13}C/^{12}C$, $^{17}O/^{16}O$ and $^{14}N/^{15}N$ all amount to 10 to 40 %, consistent with the observed variability in p Oph.

1. Introduction

Valuable information about Galactic nuclear evolution has been obtained through studies of the relative abundances of the CNO nuclides, the different nuclides being produced and ejected by stars of different initial masses and evolutionary states. In the interstellar medium, isotope ratios offer accuracy in the measurement of stellar and interstellar abundances, greatly aiding in models which attempt to follow the ongoing nuclear evolution (c, f., Wannier, 1980; Langer and Penzias 1990). Of all measured abundance ratios, the millimeterwave observations of interstellar $C^{17}O/C^{18}O$ have yielded the most precise abundance data outside of the Solar System (Table 1). In interstellar clouds, measurements of the $J=1\rightarrow0$ emission line strengths have a very small scatter in the ratio, ranging from 0.24 to 0.30, with 0.27 being a good typical value (Wannier et al., 1976; Penzias, 1981; Bujarrabal et al., 1983; Guélin et al., 1982). Furthermore, the fact that the observed values in **all clouds** significantly exceeds the terrestrial value (O. 186) has been cited as evidence for galactic nuclear evolution. Additional evidence for evolution comes from $^{17}O/^{18}O$ observations of -20 red giant stars (SC, C, M and cool super-giant stars). In every case, the stellar ratio significantly exceeds that in every interstellar cloud, indicating that material enriched in ^{17}O is regularly injected into the ISM on solar mass scales (Wannier, 1985; Kahane et al., 1992; Harris et al., 1987). Despite this evidence implying evolution, all interstellar clouds appear to have the same abundance ratio, even those near the Galactic Center' (Wannier, 1989).

Table 1: Abundance Ratios of the CNO Nuclides

isotope ratio	$^{17}O/^{18}O$	$^{13}C/^{12}C$	$^{17}O/^{16}O$	$^{18}O/^{16}O$	$^{14}N/^{15}N$
Solar Abundance	1/5.5	1/89	1/2630	1/490	273/1
	(Values with respect to solar abundance)				
Outer Galaxy	1.5±0.1	1.4±0.3	1.1±0.3	1.0±0.2	1.1±0.15
Galactic Center	1.6±0.1	3.2±0.8	2.9±1.2	2.0±0.8	2.5±0.6
Red Giants	9 (2.2-16)[a]	6 (1-16)[a]	6 (2.4-16)[a]	0.9±0.3[b]	(≥1-15)[b]

[a] Wannier, 1985, Kahane et al,, 1992; numbers in parentheses indicate a range in the data
[b] Wannier, 1989.

Within the Solar system observations of the oxygen isotopes have also given rise to intriguing results, namely the presence in meteoritic material of pre-solar material significantly enriched in ^{16}O. The data come from several carbonaceous chondrites, including Allende and Murchison (Clayton, Grossman, and Meyada, 1973; Clayton, 1981; Anders, Virag, Zinner, and Lewis, 199 1). A key feature of the meteoritic data is the availability of three stable oxygen nuclei, which allow effects of chemical fractionation to be distinguished from abundance variations. The meteoritic determinations are not compatible with simple chemical fractionation, and have been interpreted as indicating the operation of a single, enriching pre-Solar event, such as a supernova (Clayton and Mayeda, 1977). Other evidence for inhomogeneities comes from measurements of $^{12}C/^{13}C$. Recent measurements of Murchison (Bernatowicz et al., 1991) reveal ratios between 7 and 1330 for different spherules, as compared to the average solar system value of 89, or the average galactic ratio of 60 to 70 (Langer and Penzias 1991). This difference has been taken as evidence that these spherules are stellar grains from novae and red giant winds (low ratios) or supernovae (high ratios) that have survived the interstellar] medium, survived the planet formation stage, and have been incorporated into meteorites. In the Orgueil meteorite, a very large ^{1}70/180 has been taken to indicate significant enrichment, probably from a red giant or asymptotic giant branch star (Huss et al., 1994; Hutcheon et al., 1994). Interstellar and solar isotopic measurements also provide clues regarding comet formation. For example, Comet Halley appears to have a significantly different value (65±9) than that in the inner Solar System (Wyckoff et al.,1989).

The observed properties combine to make $^{17}O/^{18}O$ ideal for studies of small-scale variations in galactic enrichment, studies which may indicate how new material is incorporated into the ISM. The goal of the present study is to determine whether solar-mass sized interstellar abundance inhomogeneities persist within star-forming molecular clouds and, if so, whether they are likely to influence the abundances in forming stars. If such inhomogeneities exist, then they may have existed in the pre-Solar cloud. Such a possibility would not only modify our view of nuclear evolution, but it would seriously undermine one of the basic assumptions which is always made when modeling the evolution of abundances in the Galaxy: namely that the Solar System (or terrestrial) values for the abundances of the nuclides can be taken to be the average galactic interstellar value when the Solar System formed, some 5 Gyr ago.

2. Observations

What type of source (if any) is appropriate to track abundance inhomogeneities on the scale of a solar mass? At a typical cloud density of 10^3 cm^{-3}, one MO would uniformly fill a box 1/3 pc on a side, subtending 4 arcmin at a distance of 300 pc. That scale varies as $\rho^{-1/3}$, so that a gas density of 10^4 would still subtend about 2 arcmin, a size scale which can be readily resolved by single-dish millimeter-wave telescopes. It also indicates that appropriate sources should be less than 500 pc distant, preferably significantly closer. A good astronomical source for such a project should therefore be nearby (to allow abundance variations on the scale of 1 $M_\odot$) and have strong $C^{18}O$ lines (to ensure that a ratio can be measured). To check for variability in the ratio, the object should have" extended $C^{18}O$ emission.

Table 2: Source List:

Object	R.A.	Dec.	Observed Species	Observing dates
B335	19 34 35	+07 27 24	$C^{17}O$, $C^{18}O$, ^{13}CO	2/95
L134	15 51 30	-02 43 31	$C^{17}O$, $C^{18}O$, ^{13}CO	2/95
ρ Oph (L1688)	16 23 35	-24 19 00	$C^{17}O$, $C^{18}O$, ^{13}CO	12/91, 6/94

We chose 3 objects for our initial study: p Oph (L1 688), L 134N and 13335. p Oph is particularly appropriate for the present study, being near by (150 pc), and having strong (~2-3K) emission lines of $J=1\rightarrow0$ $C^{18}O$. It is also a site of active low- and intermediate-mass star formation, and may therefore relate to conditions in the pre-Solar nebula. 1.134N is located at a similar distance (160 pc), and has strong (1 to 2 K) $C^{18}O$ lines (Swade, 1989), but it is a more quiescent region without active star formation. B335 is in the Aquila Rift, and is a site of active low-mass star formation and has line intensities comparable to those in L134N, but is located as a somewhat larger distance (-400 pc). Reference positions and observing dates are given in Table 2. Pixel locations are given below.

How can observations be made to minimize the contribution from measurement errors? Because we are interested in the point-to-point variability of $C^{17}O/C^{18}O$, we are only sensitive to point-to-point variations of the gain ratio for the two isotopomers. One method which has been used to limit such variability is to observe the two isotopomers simultaneously, a reasonable approach when the spectral lines are close in frequency (c f., Wannier et al., 1991). However, in the case of $C^{17}O$ (1 12.4 GHz) and $C^{18}O$ (109.8 GHz), that is not practical. In principal, these two species could be observed in opposite receiver sidebands, but requires an accurate knowledge of the relative gains in the two receiver sidebands. We have chosen alternative approach: to make simultaneous maps of each isotopomer, minimizing point-to-point variability of calibration uncertainties, and to take ratios of maps of the two isotopomers. This approach may yield errors in the average ratio over the map, but not in its point-to-point variability.

The present observations were carried out with the 15-beam array receiver (QUARRY) of the Five Conege Radio Astronomy Observatory (FCRAO), operating at the $J=1\rightarrow0$ transitions of $C^{17}O$ and $C^{18}O$. Hyperfine splitting of the J= 1 level of $C^{17}O$ causes the $J=1\rightarrow0$ transition to consist of a triplet ($F = 3/2\rightarrow5/2, 7/2\rightarrow5/2$ and $5/2\rightarrow5/2$) with frequencies of 112,358.780, 112,358.988 and 112,360.005 MHz (Frerking and Langer, 1981) and with relative strengths of 2, 4 and 3 respectively. The FCRAO array receiver has -0,84 arcmin pixels, located in a 5(RA) x 3(Dec) pixel footprint (Table 3). The reported observations occurred in three sessions: 26-28 December, 1991, 19-21 June, 1994 and 11-13 February, 1995 (Table 1). In the 1991 observations wc obtained QUARRY maps in p Oph, with good (winter) observing conditions. The second of these two observing sessions was scheduled with the express purpose of confirming the earlier results, but was twice delayed due to poor weather conditions. In 1994, we re-observed p Oph, though under less favorable observing conditions (higher sky opacity), leading to higher effective system temperatures. Although we expected some variability, at least in the map-average isotope ratios, we detected none (see section 5)! In 1995, we mapped fields in L134N and B335.

The observations in 1991 were obtained with a 32 channel filter bank spectrometer, having a resolution of 250 kHz (Erickson et al. 1992), In 1994, a new autocorrelation spectrometer with 1024 channels per array pixel was in operation, and the data were obtained at 20 MHz corresponding to a channel spacing of 19.5 kHz. All observations were calibrated by a chopper wheel which allowed switching between the sky and an ambient temperature load. Because relative calibration of the $C^{18}O$ and $C^{17}O$ data was of interest, the data were obtained by alternating the maps so that the relative calibration was preserved. In 1991, data were obtained by position switching between observations on the source and a reference position. Observations in 1994 and 1995 were made in frequency switching mode. "l'he half power beam width (θ_{FWHM}} of the 14 meter telescope and the forward scattering efficiency (η_{FSS}) were determined from observations of Jupiter and the Moon. The results at 115 GHz (CO) and 110 GHz (^{13}CO and $C^{18}O$) are, respectively, θ_{FWHM} = 45" and 47". For $C^{17}O$, we interpolated, yielding 46". The value of η_{FSS} is 0.7 throughout the range 109 to 115 GHz. The pixel locations arc given in Table 3, in units of arcmin relative to the coordinates given in Table 2. Note that the offsets in Table 3 are in true arcmin on the sky, not in (RA) coordinate offsets,

Table 3: Pixel locations

B335 Footprint (ΔRA, ΔDec; arcmin)

	1	2	3	4	5
1	1.64, 2.48	0.88, 2.61	0.00, 2.48	-0.86, 2.61	-1.64, 2.48
2	1.64, 1.64	0.88, 1.78	0.00, 1.64	-0.86, 1.78	-1.64, 1.64
3	1.64, 0.84	0.88, 0.87	0.00, 0.84	-0.86, 0.87	-1.64, 0.84
4	1.64, 0.00	0.88, 0.04	0.00, 0.00	-0.86, 0.04	-1.64, 0.00
5	1.64,-0.81	0.88,-0.87	0.00,-0.81	-0.86,-0.87	-1,64,-0.81
6	1.64,-1.64	0.88,-1,70	0.00,-1.64	-0.86,-1.70	-1.64,-1.64

L134N Footprint (ΔRA, ΔDec; arcmin)

	1	2	3	4	5
1	-0.03, 2.48	-0.80, 2.61	-1.67, 2.48	-2.54, 2.61	-3.32, 2.48
2	-0.03, 1.64	-0.80, 1.78	-1.67, 1.64	-2.S4, 1.78	-3,32, 1.64
3	-0.03, 0.84	-0.80, 0.87	-1.67, 0.84	-2.S4, 0.87	-3.32, 0.84
4	-0.03, 0.00	-0.80, 0.04	-1.67, 0.00	-2.54, 0.04	-3,32, 0.00
5	-0.03,-0.81	-0.80,-0.87	-1.67,-0.81	-2.54,-0.87	-3,32,-0.81
6	-0.03,-1.64	-0.80,-1.70	-1.67,-1.64	-2,54,-1.70	-3.32,-1.64

ρ **Oph**: Eastern Footprint (ΔRA, ΔDec; arcmin)

	1	2	3	4	5
1	-2.52,6.68	3.27,6.80	-4.18,6.68	-4.97,6.80	-5.84,6.68
2	-2.52,5.02	-3.27,5.09	-4.18,5.02	-4.97,5.09	-5.84,5.02
3	-2.52,3.36	-3.27,3.38	-4.18,3.36	-4.97,3.38	-5.84,3.36

ρ **Oph**: Western Footprint (ΔRA, ΔDec; arcmin)

	1	2	3	4	5
1	-5.03,6.68	-5.78,6.80	-6.69,6.68	-7.48,6.80	-8.35,6.68
2	-5.03,5.02	-5.78,5.09	-6.69,5.02	-7.48,5.09	-8.35,5.02
3	-5.03,3.36	-5.78,3.38	-6.69,3.36	-7.48,3.38	-8.35,3.36

In the case of p Oph the overlapping map locations are the westernmost two columns in the eastern footprint (columns 4 and 5) and the easternmost two columns (1 and 2) of the western footprint. For the B335 and theL134 data, the offsets between the two footprints were such that the first row of the second (southern) footprint was placed midway between locations of rows 1 and 2 of the first footprint. Since the rows are spaced by about twice the separation as the columns (about -1.6 arcmin in Dec vs. -0.8 in RA), the two footprints together yielded a regularly-spaced grid of 5 columns and 6 rows.

4. Results and Analysis

The observational goal is to measure spatial variations in $C^{17}O/C^{18}O$, and to obtain the absolute value of the ratio if possible. We examine in some detail possible sources of error, both in the measurement (are we truly measuring ratios in the line-of-sight brightness temperatures?) and in the interpretation (can these brightness ratios be interpreted as abundance variations?). Instrumentally, the easiest error to deal with is detector noise. It is readily measured and statistically benign. Its effect was minimized by calculating the ratio, weighting by the square of the $C^{18}O$ emission line intensity (Wannier and Sahai, 1987). Due to the known, $C^{17}O$ fine structure, the weighted mean was actually made between the observed $C^{17}O$ spectrum and the $C^{18}O$ spectra convolved with the known $C^{17}O$ fine structure. Third order polynomial baselines were removed from all spectra before taking the ratio.

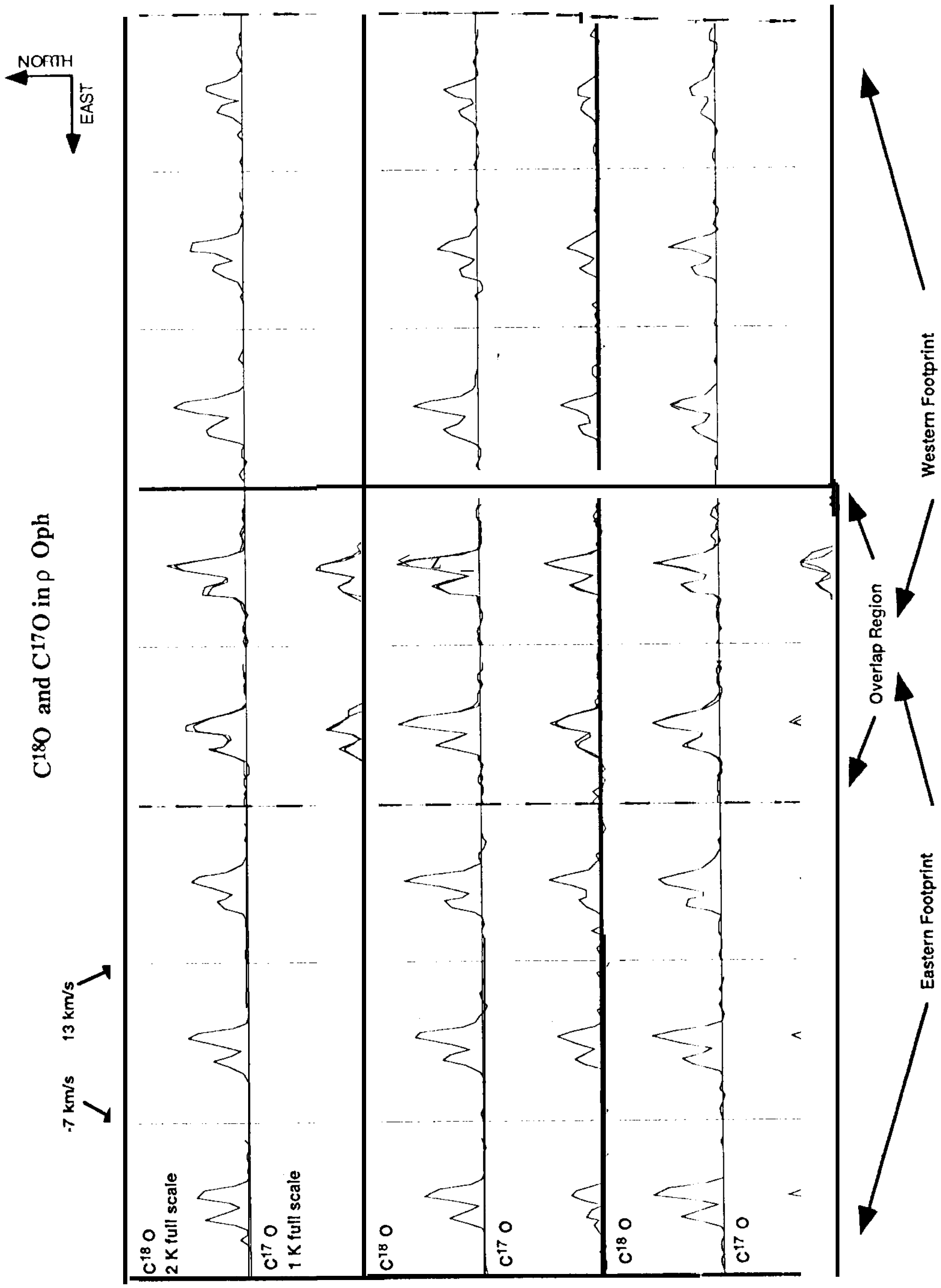


Fig. 1 Data from 1991 December are shown for the source ρ Oph, taken with the FCRAO array receiver having a three (Dec.) by five (R.A.) footprint. In the plot, the first two rows correspond to $C^{18}O$ and $C^{17}O$ spectra from the same Declination, offset on the plot to make them easier to see. The J=2→1 $C^{17}O$ spectra (rows 2, 4 and 6) are a triplet comprised of three fine structure components, seen as a stronger and broader feature (the blended F = 3/2→5/2 and 7/2→5/2 components) and a second, weaker one (the 5/2→5/2 component). The $C^{18}O$ spectra (rows 1,3 and 5) are shown convolved with the same fine structure components, to enable a more meaningful comparison of the spectra from the two isotopomers.

Other contributions to measurement error may be collect ively termed “systematic errors”. By using the array receiver, we are insensitive to several of these, namely those affecting all pixels simultaneously, such as variations in weather conditions, or calibration errors. Since our primary goal is to measure spatial variations, we need not be overly concerned by errors in the absolute ratio. Nonetheless, care was taken to obtain the $C^{17}O$ and $C^{18}O$ data in similar conditions (weather and elevation angle) to minimize such effects. We have taken two approaches to look for systematic errors: (1) offsetting the array footprint in a way which allows overlap in the maps (Table 4), and, (2) taking independent data at different observing dates (Table 5). In both cases, we can look for differences larger than those expected fı om the known receiver noise, In detail, we have propagated the receiver noise through the mathematical operations involved in taking the line ratio (baseline removal, convolution, weighted intensity calculation), and have compared this to the measured differences. Then we calculated the probability of achieving the observed difference based on the magnitude of that propagated error alone, using the χ^2 statistic and the probability based on evaluation of the incomplete gamma function as described by Press et al. (1986).

Table 4: Pixel-dependent relative gain variations in ρ Oph
(C^{17}O/C^{18}O in % un[illegible]; 1991 data)

(map column ----->)	4	5
Western pixels of East footprint	30±2	29±2
Eastern pixels of West footprint	29±2	33±1.5
Western pixels of East footprint	29±2	33±2
Eastern pixels of West footprint	27.4±1.3	29.0±1.3
Western pixels of East, footprint	33±2	28±2
Eastern pixels of West footprint	30±2	29±2

The source used to test for pixel-dependent errors is ρ Oph, where the CO emission is extended relative to the FCRAO mapping footprint, so that ratios can be obtained from all pixels. Spectra from the December 1991 observing session are presented in figure 1, displaying both the C^{17}O spectra and the C^{18}O spectra following convolution by the C^{17}O fine structure. A cursory examination of the overlap region shows that the spectra from the different footprints are nearly identical, to the point that it is difficult to see two spectra for the lower-noise C^{18}O spectra. These results are made quantitative in Table 4, where the C^{17}O/C^{18}O ratio is given for the (nearly-) identical mapping points in the overlap region (see Table 3). The measured ratios are statistically indistinguishable, the weighted mean difference (west-cast) being 0.8± 1.1. The χ^2 statistic, allowing for a systematic offset in the two data sets is 6.6 for the 6 data points, yielding a 2570 likelihood of achieving such a set of differences from the detector (mixer) noise alone. The χ^2statistic, not allowing for systematic offset is 7.2, which would be exceeded with 30% likelihood from the mixer noise. Because these measured ratios arc among the most accurately determined in our data set, we conclude that we do not have significant, pixel-dependent systematic errors. There is also no indication, among observations of the three clouds, that certain pixels have systematically large or small ratios.

Table 5: Re-observation of the ρ Oph map
(C^{17}O/C^{18}O in % units; comparison of 1991 and 1994 data)

column	1	2	3	4	5	6	7	8
1991	29±2	37±2	24±2	29.4±1.4*	31.5 ±1.2*	28.7±1 .5	28±2	36±3
1994	29±7	29±7	22±7	. 30±5*	28±4*	40±7	27±10	38±10
1991	27±2	30±2	32±2	27.9±1.1*	30.2±1.1*	26±2	37±3	31±3
1994	32±6	37*5	34±4	30.4*3*	26±4*	33±6	20±11	14±14
1991	38±2	34±2	29±2	31.5±1 .4*	28.5±1.4*	24±2	29±3	27±4
1994	37±6	39±6	29±7	27±4*	33±6*	15±8	32t10	33±13

* For these positions, the two easternmost pixels in the western footprint coincide (very nearly) with the two westernmost pixels of the eastern footprint. The average is reported here.

A second test was to re-measure the ratios by independent observations, carried out during different observing runs. These results are presented in Table 5, where the new and the old ratios are presented for each pixel. In the overlap region of the two footprints, where there are two old and two new values, we use a weighted mean of the values from the two footprints when comparing the new and the old data sets. We find that there is no measurable offset in the values of C^{17}O/C^{18}O between the observations made at two different dates, either in the mean value of the maps, or in the (significant) spatial variations of the ratio. The difference (1991-1994) in the mean value of the ratio is -0.2±1.2%, in the sense that the mean ratio in the second epoch was marginally larger than that of the first epoch, which was 30.3%. Based on the χ^2 statistic (17.7 for the 24 points), the probability of exceeding the observed difference is 81 % based on the receiver noise alone! From this we can reach several conclusions, two of which are important to the present paper: (1) there are no significant errors causing the spatial variations in the ratio to exceed that expected on the basis of the noise statistics alone; (2) the propagated receiver noise estimate adequately accounts for any observed variations; and (3) (not necessary for the primary goal of measuring spatial variability) the absolute ratio is apparently trustworthy as well, as evidenced by the lack of any secular variations in the ratio.

As a result of our observational checks, we are confident that the measured line ratios truly reflect ratios in the astronomical line-of-sight brightness temperatures, The resulting maps of intensity ratio are given in Tables 6a to 6c.

Table 6a: $C^{17}O/C^{18}O$ in B335 (% units)

-----	-----	36±10	21±7	39±13
37±12	37±10	36±6	33±7	17*10
29±7	32±5	29±4	22±4	39±8
6±11	36±6	36±3	33*5	35*10
1±14	29±10	35±5	40±5	-----
18±14	26t13	26±8	21±13	-----

The mean value in B335 is 31.1± 1.2%, with χ^2 = 32 (16% likelihood) for achieving the observed variation from the detector noise alone. l'bus, the evidence for variation in this source is not statistically significant.

'l'able 6b: $C^{17}O/C^{18}O$ in L134 (% units)

28±5	34±4	27±6	29±7	22±6
21±4	28±4	28±5	35±6	23±6
36±4	36±5	31±3	30±4	19±5
30±3	35±5	18±3	39±4	31±4
31±4	40±4	37*4	26±5	33±4
34±5	28±6	25±5	27±5	32±5

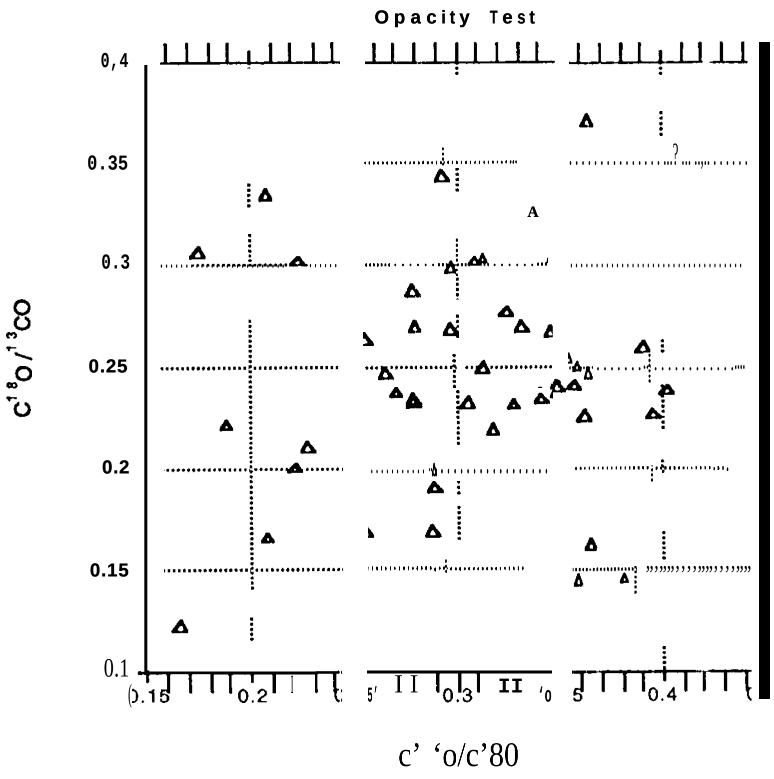
The mean value in 1.134 is 29.6± 0.8%, with χ^2 = 55 (0.2% likelihood) for achieving the observed variation from the detector noise alone. Although statistically significant, we do not interpret this variation as a definite result until additional observations can confirm it in detail.

Table 6c: $C^{17}O/C^{18}O$ in ρ Oph (% units; 1991 data)

29±2	37±2	24±2	29.4* 1.4	31.5±1.2	28.7±1.5	28±2	36±3
27*2	30±2	32*2	27.9± 1.1	30.2±1.1	26±2	37*3	31±3
38±2	34±2	29±2	31.5* 1.4	28.5* 1,4	24±2	29±3	27±4

The overall average in ρ Oph is 29.9± 0.36%. 'l'he χ^2 statistic of these values being consistent with a constant value is 77.6 for the24 mapping points, yielding a 0.00001% likelihood of achieving the observed variance given the known detector noise. We interpret this as significant, especially as maps made on two different dates produce the same locations for significantly low and high ratios.

Another source of error is in the interpretation of such intensity ratios as isotope abundance variations. Line saturation (optical depth effects) and chemical fractionation are both contenders in this category. Optical depth effects using the J= 1 →0 rotational transition are not generally expected to be a serious problem, because both isotopomers have weak (much smaller than, say, ^{13}CO or CO) lines, and have already yielded ratios with very small scatter among different interstellar clouds with widely varying emission line intensities (Encrenaz et al., 1973; Frerking, Langer and Wilson, 1982). We have tested for saturation directly, by making use of the ^{13}CO maps obtained for each source. In Figure 1, we present a correlation plot of $C^{17}O/C^{18}O$ vs. $C^{18}O/^{13}CO$ based on the B335 and the L134 maps. If, indeed, a $C^{18}O$ spectral line were significantly saturated (evidenced by a large $C^{17}O/C^{18}O$ ratio), then we would expect a corresponding saturation of ^{13}CO as evidenced by a large $C^{18}O/^{13}CO$ ratio. In figure 1, that would yield a positive correlation. None is evident!. A more stringent test is to look only for ratios which are significantly smaller than the average, reasoning that line saturation, if present, would always operate to make the $C^{17}O/C^{18}O$ ratio larger than its optically thin value. Therefore, we have examined the p Oph data, eliminating **all** ratios falling 2σ or more above the mean value, in our case eliminating all ratios (5 of them) larger than 32%. This would be expected to increase the likelihood of randomly achieving the observed distribution for two reasons: (1) about half of the significantly deviant numbers are not even considered (the large ones), and (2) we recalculate a new (lower) mean value which makes the low-lying numbers seem less deviant. Even with this restricted view of the p Oph data, we find that the result is very unlikely to be explainable in terms of the detector noise: the χ^2 analysis yielding a likelihood of 0.3%. Because the detector noise can fully account for pixel-to-pixel and for secular variations on the data, we conclude that there are real abundance variations in p Oph.



Chemical fractionation is a more difficult effect to test observationally, because it would be indistinguishable from a variation in the underlying isotope ratio. Significant fractionation of the oxygen isotopes has never been seen to date, and is not expected on theoretical grounds (Langer et al., 1984). Such a process could, in principal, lead to small-scale, small amplitude variations if the underlying conditions leading to such fractionation were to vary on a solar-mass scale. The best approach is to see if such variations exist and, if so, whether they correlate with obvious physical conditions such as temperature, or ionization fraction.

A third, interpretational effect, which would tend, rather, to diminish than to enhance the observed variations in the ratio, is the averaging of abundance ratios (superposition of clumps) along the line-of-sight. Suppose (cf. cloud model of Tauber and Goldsmith, 1990) we assume a 100 MO cloud to be composed of "clumps" of about 1 MO exhibiting random clump-to-clump abundance variations. Any line-of-sight would contain 4 to 5 clumps, reducing the observed abundance variations by about a factor two below the clump-to-clump abundance variations. Our approach to this effect is to accept that our observed variations probably understate any underlying abundance variation by a factor 1 (1 line-of-sight clump) to 5 (25 clumps). Because late-type evolved stars enrich ^{17}O in the ISM by factors of 2-10, int cresting limits can nonetheless be set.

5. Conclusions

Abundance inhomogeneities, on solar mass scales, could seriously affect our understanding of the evolution of Galactic abundances. In nearby molecular clouds ($d < 500pc$) single-dish millimeterwave telescopes provide adequate resolution to track such inhomogeneities. Existing measurements of the interstellar $^{17}O/^{18}O$ ratio indicate that it may be the best abundance ratio to use in trying to detect such inhomogeneities.

The measured ratio has the smallest scatter (<10%) of any measured abundance ratio, consistent with a uniform ratio in all observed interstellar clouds)

Active enrichment (by factors of 2.4 to 16) is seen on solar mass scales from red giants.

There is no evidence for a galactic gradient, yet the solar system displays evidence for both microscopic (from meteorites) oxygen isotope anomalies and an average abundance distinct from the current interstellar value.

Using the $J=1\rightarrow0$ transitions of $C^{17}O$, $C^{18}O$ and ^{13}CO, we have made maps of emission line intensities in three nearby clouds (B335, L134 and ρ Oph) using the FCRAO array receiver. We have concluded that there are no significant measurement errors causing the variations in the ratio to exceed that expected on the basis of the detector noise alone, based on statistical evaluations of overlapping maps, and of maps made on different dates. Furthermore, the absolute ratio is apparently trustworthy, a finding not vital to our evaluation of spatial variability..

Conclusions for the three observed sources vary. In B335, the observed ratios are statistically consistent with a constant $C^{17}O/C^{18}O$ ratio. In L134, evidence for a spatial variation is statistically significant (0.2% likely, based on propagated detector noise alone), but we do not claim this variability as definite until we can obtain a confirming ratio map. In p Oph, the observed variability is significant beyond question (0.00001% likely, based on detector noise alone), and the observed variability y repeated in two independent maps. Based on cloud models, we estimate that real variability, on solar mass scales may exceed that observed by factors of a few (1 to 5), due to line-of-sight averaging. Hence, our observed column density abundance variabilities are lower limits to spatial variabilities on solar mass scales.

Based on the lack of variability from source to source, and on a lack of obvious pattern in the abundance irregularities, we conclude that the observed variability is unlikely to result from chemical fractionation. In order to place this conclusion on a sounder footing, additional maps will be required, allowing a more detailed comparison between the observed ratio and physical conditions within the cloud, such as temperature and ionization fraction. Our resulting conclusion is that we have detected spatial variability in the $^{17}O/^{18}O$ oxygen abundance ratio in p Oph, probably resulting from local enrichment. The observed variability in the column abundance ratio ($N(C^{17}O)/N(C^{18}O)$) is $\pm20\%$, implying a likely spatial variation several times higher, due to likely line-of-sight averaging.

Such a conclusion, if substantiated, would have important implications for our understanding of Galactic nuclear evolution. If such variations can find their way into forming stars, then we must view with suspicion conclusions based on differences between solar abundances (taken as typical of 5 Gyr ago) and those in the present-day interstellar medium. Such differences, in $^{17}O/^{18}O$, $^{13}C/^{12}C$, $^{17}O/^{16}O$ and $^{14}N/^{15}N$ all amount to 10 to 40 %, consistent with the observed variability in p Oph.

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